Irradiation effect of hot electronic beams on parylene films

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Abstract   The multi-layer parylene (PP) films were irradiated by hot electrons with a dose of 2×10^{16} cm^{-2}. The irradiated and non-irradiated films have been examined by FT IR, UV-Vis and strain-stress measurement instruments. The results show that the damage has been created for irradiated films, including benzene rings and broken C-C bonds. The absorbance on the vision light increases and the Yang's modulus decreases greatly in irradiated films with the worse toughness. The experimental conditions determine whether these effects hinder hydrodynamic instability or not.

Key words   Irradiation chemical, Hot electron irradiation, Parylene

1   Introduction

ICF(inertial confinement fusion) experimental result is driven by instability development that is important phenomenon in many physics process[1,2]. In design of physical experiment and preparation of target, various factors that may induce instability should be analyzed, so as to restrain it to certain range. The origin for instability in ICF experiment includes laser imprinting, symmetry of target, surface roughness, internal defects in target[3,4]. It has been demonstrated that all the above-mentioned inevitable sources of instability in early stage of physical experiment can be controlled. However, the other kind of instability source produced in the course of explosion, such as effect on hot electronic beam produced in hohlraum or Corona area of target irridiating on shell, effect on the structure of the target by the penetrating hard X-rays, effect on surface and subsurface targets by super fast ion, are less studied. This process closely links to energy deposition and implosion, whose instability is covered up with the one from unsatisfactory factors such as initial experiment and target defects, making the instability of the particular process indistinguishable. For the Explosion Physics problems need to be further studied, it is necessary to explore the instability resulted from the irradiation on the target shell by hot electron and hard X-rays in the course of explosion. In addition, the Pulse width in hohlraum is ns scales, and pulse strength in 10^{16}–10^{18} cm$^{-2[5]}$ for electron beam in ICF experiment, which can't be realized with ordinary accelerators, therefore, thermal electron damage effect experiment is rarely done under these parameters.

At present, the preferred target shell materials with ICF experiment are Be(Cu), CH(Ge,Si), and C(diamond)[6,7]. Comparatively, CH-base shell is the one that is most likely realized technically. In this paper, damage effect of hot electron on the target shell thickness and that of hot electronic energy range on the shell are simulated, adopting parylene (PP) C:H=1:1 with samples. And the structure and state of materials prior to ablation zero point is studied. Accurate instability factors are given for further study of instability phenomena in ICF explosion experiment.

2   Experimental

The experiment was performed on an accelerator in Sichuan University, with an intensity of output electronic beams at the accelerator port of 2×10^{12} cm$^{-2}\cdot$s^{-1}, a beam scanned area of 100 cm× 100 cm, a single electronic energy between 1.75 MeV and 1.8 MeV, a section of air gap of 37 mm between the vacuum chamber export and the sample. Electronic energy of 1.75 MeV was adopted for calculation of single electron at incidence sample. As shown in Fig.1, a copper sheet with thickness of 0.462 mm is placed in

front of the sample in order that the electronic energy can be attenuated to hot electronic energy range.

With size of 25 mm (l) ×25 mm (w) ×35 μm(t), the samples were prepared via chemical vapor deposition method, and stacked in multi-sheet. The total thickness is greater than the range of electron at PP after passage of the copper sheet. As shown in Fig.1, The accumulated density of the irradiation thermal electronic dosage is $2×10^{16}$ cm^{-2}.
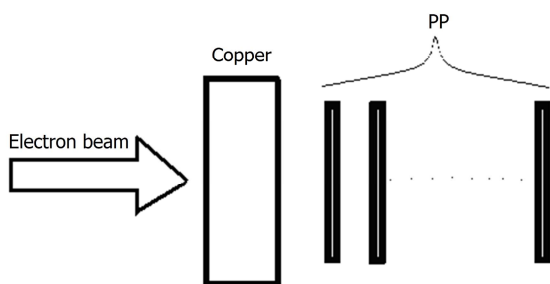

Fig.1   Schematic for experiment.

The irradiated and nonirradiated samples were studied by FT IR (Fourier Transform Infrared spectroscopy), UV-Vis (Ultraviolet-Visible Spectroscopy) spectroscopies and tension instrument. The PP films passed through by hot electron and film un-irradiated were selected for analysis. The FTIR measurements were carried out with NICOLET 6700 system in absorption mode. The resolution of the system is set at 4 cm^{-1}, and the analytical wave number is in the range 400–4000 cm^{-1}. The UV-Vis measurements were carried out with a Perkin Elemer Lambda 12 system in transmission mode. The resolution of the UV-Vis spectrometer is set at 1 nm, and the analytical wavelength is in the range 300–1000 nm. The tension measurements were carried out with a KD serials system WDT-10 model instrument.

3   Monte Carlo calculations of electronic stopping power

Two-object collision approximate is used to deal with multi-object collision problem of electron vs. target ion and electron[8]. Since the energy loss induced by target electron is much greater than that caused by nucleus, the damage of the material is mainly caused by energy loss of target electron. The electronic energy loss caused by the target is expressed as follows.

$$\frac{dE}{dx} = \frac{4\pi e^4 Z_2 Z_1^2 n}{m_e v^2}[\ln(\frac{E}{<I>}) + \delta_1]$$

where Z_1 denotes effective charge of incident ion; Z_2 stands for effective charge of target atom; E is incident energy; m_e denotes electronic quality; n is target electronic density, $<I>$ denotes average ionization energy of target under normal temperature; δ_1 is correct for formula under normal temperature. Generally energy loss caused by target electron is much greater than that caused by target ion, except out of the range, therefore, it is enough to express energy loss of the incident particle with energy loss induced by target electron.

Monte Carlo method is used for calculation of electron incident on PP material. The calculated result is shown in Fig.2. In the interested hot electronic energy region, energy loss of the incident electronic unit path tends to approximately a linear drop on logarithmic coordinate. The range is 63.5 μm and 25.8μm for energy of 100 keV and 60 keV, respectively. The longitudinal straggling increases with the range. It even reaches a proportion of 1:2. The lateral straggling radius increases with the range, whose proportion to longitudinal straggling can be 1:1.
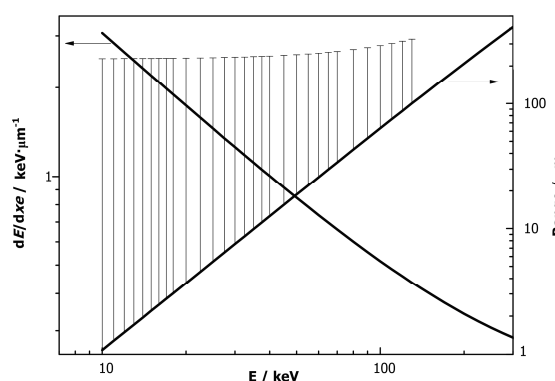

Fig.2   Curves of electronic energy loss and range and error vs. electronic energy in PP.

4   Results and analysis

Un-irradiated samples are found colorless and transparent, while the ones irradiated are yellow and opaque. This shows that chromophoric group occurs with the material irradiated. There are two kinds of elements in PP material: C and H, and two kind groups: methylene and benzene ring. It is known that the

chromophoric group is likely to be precipitation of C element or production of new group.

In order to indicate the chemical state after PP material irradiated by 100 keV hot-electron, samples pass by electron at 100 keV according to Monte Carlo calculation results and several samples followed were selected for FT IR spectrum as shown in the Fig.3. The chemical group of parylene contains only methylene and benzene ring, so its FT IR spectrum is considerably simple. It is seen that the absorption peaks are near 2853 cm^{-1} and 2922 cm^{-1} for symmetry or asymmetry stretch-vibration mode of methylene, near 3016 cm^{-1} for stretch-vibration mode of C-H on benzene ring, and at 1064 and 1452 cm^{-1} for skeleton-distortion-vibration mode of benzene ring[9].
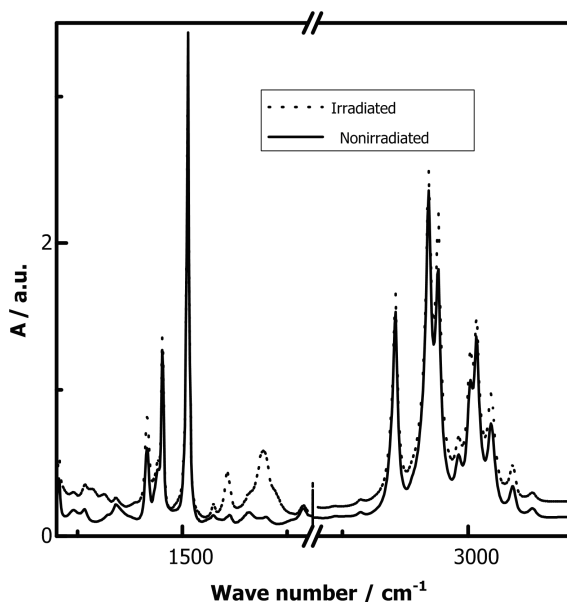

Fig.3 FT IR spectrum for samples nonirradiated and irradiated.

From comparison of samples nonirradiated and irradiated, it is known that there occurs neither shift at absorption peaks of samples irradiated, nor appearance of new absorption peak and disappearance of original absorption peak. The intensity of several featured peaks decreases or increases, for instance, the peaks of 1452 cm^{-1}, 3016 cm^{-1} for benzene ring and 2853 cm^{-1}, 2922 cm^{-1} for methylene have reduced amplitude with samples irradiated. But the peaks of 1604 cm^{-1} for benzene ring and 1697 cm^{-1} for carbonyl group have increased amplitude with samples irradiated.

By comparison of several samples irradiated, it is known that the range and range straggling simulated

and calculated conform to results analyzed on FT IR, the only difference is that the intensity of featured absorption peak of samples close to end of the range is a little smaller variety on FT IR spectrum.

Two samples are tested on UV-Vis spectrum so as to acquire light absorption feature of the samples. The test result is illustrated in Fig.4, from which it is seen that light absorption on the UV-Vis spectrum after irradiation is enhanced within the test range, and the cutoff wavelength is prolonged.
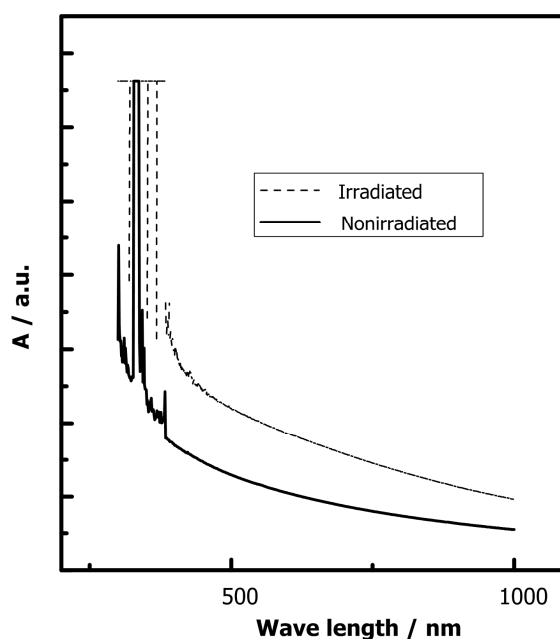

Fig.4 UV-Vis spectrum for samples nonirradiated and irradiated.

A tension instrument was used to test the change of mechanical properties of the samples. The test results are given in Fig.5, where (a) stands for curve of tension test of sample nonirradiated, and (b) denotes that of samples irradiated.

As shown in Fig.5, the curve of nonirradiated sample (a) goes with three segments (marked I, II, III in Fig.5(a)). Segment I, the stress sharply rises at the beginning, Segment II, the stress varies smoothly, yet the strain varies sharply, and Segment III, the stress drop sharply till they goes to zero. Curve of tensions test of the irradiated sample (b) goes with two segments: Segment I with a sharp rise, and segment III with a sharp drop. There is no platform segment, which has been simplified as a turning peak. The

largest force in Fig.5(a) is 26.67 MPa/cm^2, but 4.36 MPa/cm^2 in Fig.5(b). The curve also shows that the strain-rate of samples nonirradiated is 12%, and that of samples irradiated drops to less than 0.4%.
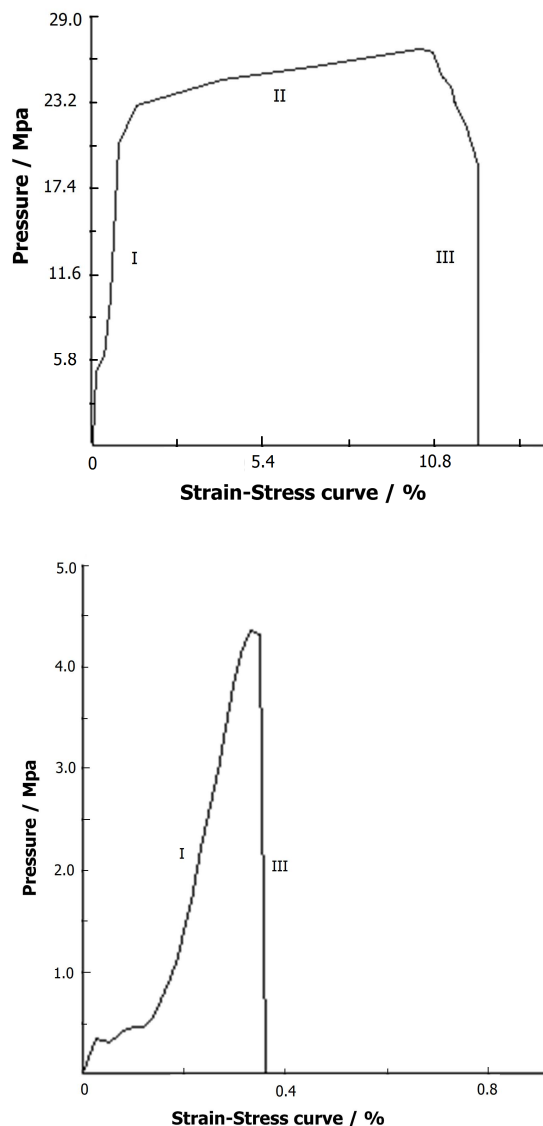

Fig.5 Curve of tension experiment for samples nonirradiated (a) and irradiated(b).

5   Discussion

Used as target shell material in hohlraum, PP material functions as confinement of fusion fuel, absorption of energy, compression of fuel[10], which makes it high quality needed.

The simulated calculation results show that hot electron of 100 keV is able to penetrate PP material of about 35 μm. After irradiation damage is done to the PP material, the fusion fuel is heated by the dump energy. Energy of single electron, which deposited in the fusion fuel is up to dozens of keV. This increases the difficulties for compression.

The tested results from infrared spectrum shows that valence linkage breaks occurred while some damage occurred inside the PP material under intense hot electronic irradiation, and inner defects of the material inevitably produced, and the energy state of the material was increased. This is helpful to increase ablation speed of the target shell. The increase of the absorbance at 1604 cm^{-1} indicates that some benzene-like material was formed during hot electron passing through PP films. This phenomenon is analogous to heavy ions irradiation to PP material[11]. Energy loss increases at the end of the hot electron range, but the infrared spectrum test result indicates that damage to material is small. This is due to the fact that some electrons are absorbed in the course of transmission and hence the total number of electrons is small when they come to the end. Enhance of peak 1697 cm^{-1} of samples irradiated in infrared spectrum, because a small amount of oxygen attached to the surface during irradiation of samples, which finally forms carbonyl.

Results on UV-Vis spectrum for samples indicate that light absorption of irradiated films increase at the visible light segment, and the cutoff wavelength moves towards the long wavelength direction. In addition to that, its appearance turns yellow. All this suggests that there exists free C element and other chromophoric group, which consistent with results from FT IR measurement and naked eyes. The effect might be better to reduce pre-heating degree of fuel.

We can know from the tension calculation experimental datum, Young's modulus of pp films irradiated becomes smaller, which indicates the mechanical strength deteriorates sharply, and the bearable strain rate becomes smaller, which means toughness of the irradiated material deteriorates. These are not a good change for ICF target shell materials that bears certain air pressure, for instance, if the air pressure is too great at the beginning of the experiment, it could make the film crack to fuel encapsulated in target sphere escape. This phenomenon should be prevented absolutely during ICF experiment.

6   Conclusion

A simulated calculation and experiment for hot electronic beam irradiation on PP films were performed. The samples nonirradiated and irradiated were tested by means of FT IR, UV-Vis spetroscopies and tension instrument. The results indicate that the hot electron might pass through shell with thickness of tens of micrometer to pre-heat fuel in ICF experiment. The shell structure would have been changed partly, which might induce instability. This helps speed up the ablation in ICF experiment. Absorption to visible light of the film is increased after irradiation. Accordingly warm-up from visible light to fusion fuels is reduced. Mechanical strength and toughness of the irradiated films deteriorates, thus the films that bears certain air pressure are possible to crack. This is determined by initial conditions of the experiment. The above-mentioned results help either inhibit instability developing during the ICF experiment or its simulated experiment or promote it. Priority of the two effects is determined by the purpose and the initial conditions of the experiment.

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